NASA TECHNICAL MEMORANDUM NASA TM-75796

THE RELATION BETWEEN TILT TABLE AND ACCELERATION-TOLERANCE AND THEIR DEPENDENCE ON STATURE AND PHYSICAL FITNESS

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(NASA-TM-75796) THE RELATION BETWEEN TILT TABLE AND ACCELERATION-TOLERANCE AND THEIR DEPENDENCE ON STATURE AND PHYSICAL FITNESS (National Aeronautics and Space Administration) 30 p HC A03/MF A01 CSCL 06S G3/52

N80-28042

Unclas 27966

Translation of "Die Abhängigkeit der Orthostase- und Beschleunigungstoleranz von Körperbau und Leistungsfähigkeit," Internationale Zeitschrift Fuer Angewandte Physiologie Einschliesslich Arbeitsphysiologie, Vol. 26, 1968, pp 205-226

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 APRIL 1980

STANDARD TITLE PAGE

1. Report No. NASA TM- 75796

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle THE RELATION BETWEEN TILT TABLE AND ACCELERATION TOLERANCE AND THEIR DEPENDENCE ON STATURE AND PHYSICAL FITNESS

5. Report Date April 1980

6. Performing Organization Code

7. Author(s) K.E. Klein, F. Backhausen, H. Bruner, J. Eichhorn, D. Jovy, J. Schotte, L. Vogt and H.M. Wegmann, Dep't. for Flight Medicine, Bad Godesberg

8. Performing Organization Report No.

10. Work Unit No.

9. Performing Organization Name and Address
Leo Kanner Associates, Redwood City, California 94063

11. Contract or Grant No. NASw-3199

13. Type of Report and Period Covered
Translation

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration, Washington, D.C. 20546

14. Sponsoring Agency Code

15. Supplementary Notes
Translation of "Die Abhängigkeit der Orthostase- und Beschleunigungstoleranz von Körperbau und Leistungsfähigkeit," Internationale Zeitschrift Fuer Angewandte Physiologie Einschliesslich Arbeitsphysiologie, Vol. 26, 1968, pp 205-226 (A69-21304)

16. Abstract Experimental studies in a group of 12 highly trained athletes and a group of 12 untrained students lead to following results: 1. During a 20 min. tilt, including two additional respiratory maneuvers, the number of faints and average cardiovascular responses did not differ significantly between the groups; 2. during linear increase of acceleration with a rate of 1 G/15 sec., the average blackout level was almost identical in both groups; 3. statistically significant coefficients of product-moment correlation for various relations; 4. the coefficient of multiple determination computed for the dependence of $+G_z$-tolerance on heart-eye distance and systolic blood pressure at rest allows the explanation of almost 50 % of the variation of $+G_z$-tolerance, instead of 16 %, resp. 23%, if the two independent variables are used singly; 5. the max. oxygen uptake showed the expected significant correlation to the heart rate at rest, but not to the acceleration-tolerance or to the cardiovascular responses to tilting.

17. Key Words (Selected by Author(s))

18. Distribution Statement
Unclassified-Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	30	

NASA-HQ

THE RELATION BETWEEN TILT TABLE AND ACCELERATION-TOLERANCE AND THEIR DEPENDENCE ON STATURE AND PHYSICAL FITNESS

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Summary

Experimental studies in a group of 12 highly trained athletes (VO$_2$max: 4.6 l/min) and a group of 12 untrained students (VO$_2$max: 3.4 l/min) lead to the following results: 1. During a 20 min tilt (90^o), which included two additional respiratory maneuvers, the number of faints and the average cardiovascular responses did not differ significantly between the groups, except for a lower heart rate level in athletes; 2. during linear increase of acceleration with a rate of 1 G/15 sec the average +G$_z$-tolerance (blackout level) was almost identical in both groups, being 6.9 for the athletes and 6.8 for the students; 3. statistically significant coefficients of the product-moment correlation were calculated in the total of both groups for the interrelation of the following variables: a) +G$_z$-tolerance and arterial blood pressure at rest (r = +0.48 to +0.55), b)+G$_z$-tolerance and heart-eye distance pressure at rest (r = -0.41), and c) total body length and responses of mean arterial pressure to tilt (in fainters: r = 0.11, in non-fainters: r = +0.47); 4. the coefficient of multiple determination computed for the dependence of +G$_z$-tolerance on heart-eye distance and systolic blood pressure at rest ($R^2_{1.23}$ = 0.492) allows the explanation of almost 50% of the variation of +G$_z$-tolerance, /205*

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*Numbers in the margin indicate pagination in the foreign text.

instead of 16%, respectively 23%, if the two independent variables are used singly; 5. the maximal oxygen uptake showed the expected significant correlation to the heart rate at rest ($r = -0.68$), but not to the acceleration-tolerance or to the cardiovascular responses to tilting.

Since Graybiel and McFarland [15] suggested tilt table testing as /206 a measure for flight fitness, the relationship of tilt table and acceleration tolerance to physical fitness has been the subject of various experimental studies. The differing results probably stem partially from the deviations in methods when measuring different quantities, and partially from the fact that individual segments of the problem were studied without connection to one another by different authors [1, 8, 20, 25, 30, 37, 48]. Interest in this problem complex has again increased greatly since the beginning of manned space travel, dominated by the search for preventative measures against the deteriorating effect of long-term weightlessness on condition [3, 5, 18, 31, 34, 36, 42-47]. A clear explanation of relationships between the various performance criteria and values, however, has not yet been presented beyond the determination of an athlete response on the tilt table deviating from the standard [45].

In the framework of studies on adjustment processes and the effect on the stress capacity of man, untrained persons and highly trained athletes were subjected among other things to a passive change of position on the tilt table and positive acceleration in a centrifuge; furthermore, the individual maximum oxygen intake during exhaustive work as well as the circulatory response during various function tests was determined. The results of these tests form the basis for the analysis in this study on the relation between tilt table and acceleration tolerance and their dependence on stature and physical fitness. The stress studies (e.g. lack of oxygen at rest and in combination with physical work) carried out on the same groups and the measurements of biochemical quantities in the blood carried out during all investigations will be published separately.

Methods

The investigations were carried out on two groups of persons, who volunteered and received payment for their services. The first group consisted of twelve healthy, untrained students, while a second group of twelve athletes had already undergone a systematic intensive endurance training for several years; the majority belonged to the national or international elite in their individual athletic disciplines (long-distance running and steeplechase, bicycle racing, speed skating). All trial persons had either become well acquainted with the equipment and methods applied in earlier studies or they were prepared correspondingly; especially for this purpose several test runs were conducted in the centrifuge.

The maximum oxygen intake ($\dot{V}O_2max$) was determined on the ergometer of the Max-Planck central workshop (Gottingen [33]) at 60 revolutions of the pedal per minute. In the case of the untrained students the work intensity was increased after a ten minute warm-up at 13 mkp/sec. continually every three minutes in steps of 2 mkp/sec. until the work was discontinued, in this group at an average of 25 mkp/sec. The athletes began after a corresponding warm-up at 21 mkp/sec. and increased in steps of 4 mkp/sec. up to the individual maximum, with an average of approx. 37 mkp/sec. The amount of oxygen inhaled and carbon dioxide exhaled was continuously determined with the basal metabolism device of the Hartmann and Braun Company, altered corresponding to the measurement of higher respiration volume; a measurement delay of 45 sec. was taken into account in evaluation. Although the trial was always disrupted upon demand of the test person, a request was made for further work especially if the pulse frequency had not yet achieved the value of 180/min and the respiratory quotient the value of 1.0. The maintenance of O_2 inhalation level during increasing stress, usually caused by reduction in utilization during steeply increasing respiration, was used as criterion that the maximum in aerobic metabolism had been achieved (on the average the maximum pulse frequency at trial discontinuation was 193/min for the untrained persons, and 189/min for the athletes, but the difference between the groups was of no statistical significance;

at the same time the average respiratory quotient was almost identical in the two groups at 1,094 and 1,098). In addition to the maximum work trial on the ergometer the circulatory response to active position change and light work was tested by means of the physical fitness test designed by Schneider [39] and the step test designed by Hettinger and Rodahl [16]. We adhered to the data in the original publications of the above-mentioned authors when conducting and evaluating the tests.

In the trial with the tilt table the beginning values of the ECG, pulse and arterial blood pressure were first determined during a rest of 15 min. in a horizontal position; these served as "rest values" for all further statistical calculations. The position of the subject was then changed by 90 degrees to an upright position within 3-5 sec. In this trial the persons were held on the table by means of foam rubber lined parachute belts; no foot or pelvic supports were employed. The vertical position was maintained for 20 min., when there was no reason for resuming the horizontal position in a shorter time. Following a method employed in the US School of Aerospace Medicine, Brooks, USA [5, 9], respiration maneuvers were carried out at defined times during the upright position as "provocation". In the twelfth minute breath was held for 30 sec. after one deep exhalation and inhalation, in the seventeenth minute a hyperventilation was called for with a given respiratory frequency also for 30 sec. The trial was discontinued by a resumption /208
of the horizontal position when signs of fainting such as dizziness, paleness, perspiration and visual problems (blackouts) occurred. During the entire trial the above-mentioned circulatory values were measured every minute. The trial was divided into the following sections for evaluation: the period between the 4th to 11th minute, the values after apnoea (12th/13th minute) and the values after hyperventilation (17th/18th minute).

The acceleration tolerance was determined in the centrifuge following the standardization recommendations [26] made for such investigations. In this procedure the test person sits upright with his head on a head rest at an angle of -10 degrees to the vertical in a moveable gondola at the end of the centrifuge arm, which swings out when the centrifuge rotates, so that the forces of acceleration act in the direction of the

longitudinal axis of the body ($+G_z$). The distance of the centrifical axis of rotation to the heart of the test person, relevant for the size of the physiological effective G forces at a given rotational speed of the centrifuge, is approx. 5 m in our arrangement. The test subject is monitored via television, an intercom and a test of his response to optical stimuli. For this purpose a central white and two peripheral red light sources were positioned at eye level in front of the test person, which were lit during the examination in irregular, rapid succession and had to be put out by pressing a button. The distance of the central lamp to the base of the nose of the test person amounted to 68 cm, the peripheral lamps arranged symmetrically on a horizontal plane were 60 cm apart. The examination was carried out in a darkened room.

The $+G_z$ tolerance was ascertained, as is usual today, by means of the increasing central light loss (CLL) occurring during increasing acceleration. This condition is characterized by a disturbance in the perception not only of the peripheral lamps while still conscious - this is already lost at low acceleration - but also of the centrally positioned light (blackout).

A unified determination of the CLL threshold was made for athletes and untrained subjects under the effect of acceleration, beginning at 1G (resting) with a constant increased velocity of 1G/15 cc ($\cong$ 0.07 G/sec). Double determinations were frequently carried out as in tilt table trials, and the results were averaged in the subsequent evaluation. In the case of eleven untrained persons and two of the athletes, the tolerance level was additionally determined in a step-wise increase in G forces with the rapid velocity increase of 1G/sec and the duration of 15 sec on a given level maximum, while the increase from the maximum of one level to the maximum of the next was carried out in steps of 0.2G. As a rule the beginning level was already 3G in this procedure, in order to avoid the influence of tiring by too many repetitions.

In addition to the above-mentioned stress data the age, weight, size, leg length (distance of the trochanter femoris from the ground) was determined for all examined persons, and as a guide for differences

dependent on size of the hydrostatic pressure variations between heart and eye, the distance between the point of the heart beat peak reached while lying down and the left outer corner of the eye was measured. Finally the total body area was calculated from weight and size.

The examinations of the untrained persons were carried out together in the spring and summer of 1966, while the athletes were examined one year later during approx. the same seasons. The effect of time of day /209 was recently described for several of the stress tests employed here [22, 24]. In order to maintain the same effect, all examinations were therefore carried out between 2:00 p.m. and 6:00 p.m. In addition room temperature was generally maintained at 20-22°C and the relative humidity was not allowed to exceed 60%.

The statistic processing of measured results was carried out with the usual procedures for calculation of the average value ($\bar{x}$) and the standard deviation (S.D.). The F test is used to check homogeneity of the random sample variants; the t test was used to check the significance of the differences in average values. The result of the t test was not the usual probability value P, but the deviations "t" used as a basis for individual P values, permitting a better differentiation of variations in average value with respect to statistical significance, employing the same number of trial persons (N). The dependence of individual measured values on one another was tested by means of calculation of the regression equation and the coefficient "r" of the product-moment correlation formulated by Pearson. All statistical calculations were carried out electronically on the table computer "Programma 101" of the Olivetti Company.

Results

Table 1 contains the personal data, the circulatory resting values measured while lying down and the results gained in the level tests, during the ergometer trials and in the centrifuge as average values separated for the two study groups. It may be seen from the table that /210 the groups differ from one another significantly in age, in weight, in size and in total surface, but in spite of random selection do not

differ in the length of leg and in spatial distance of the heart beat peak to the left outer eye corner. Furthermore, highly significant differences are found in the criteria of physical fitness, as was expected. Above all the maximum oxygen intake indicates the large difference between the two groups in the capability for performing aerobic muscular work. The measured value for the athletes is more than 35% higher for the O_2 intake of the total organism than that of the students and even 47.8% higher when the weight differences are taken into consideration; this corresponds to an average difference of more than 40% in maximum work intensity achieved at the discontinuation of ergometer trial. The differences in the step test results are comparatively smaller and, as may be seen in the t values, of less statistical significance. Only the pulse frequency indicates highly significant differences in the circulation rest values. The blood pressure values, with the exception of a slightly higher amplitude in the case of the athletes (P_s-P_d), are almost identical as is the capacity for withstanding increasing acceleration forces up to blackouts.

There were such strong indications of fainting in the case of five athletes and four untrained students during the total of 29 trials on the tilt table that the stress had to be discontinued by returning the subject to the horizontal position. Signs of fainting were noticed in two students already before the apnoea, and afterwards in the other two; two athletes fainted directly after the apnoea, three during or after hyperventilation. For those persons undergoing the tilt table studies twice, three fainted in the first trial and two in the second trial.

Table 2 presents a comparison of the values measured during tilt table studies with the values at rest. It is divided into the three sections mentioned above; no values were given for the first reaction to the immediate position change (minutes 1-3). In addition only those measurements were included in the average value calculation, which did not immediately preceed fainting, since only the effect of differing physical condition was to be compared in the groups and other factors possibly influencing circulation values were to be excluded. The t values in the last column show that only individual pulse frequency demonstrates a highly significant difference between the groups in all sections of

Table 1: Physical dimensions, fitness criteria and cardiovascular measurements at rest (a comparison of athletes and untrained persons)

	a Studenten (N = 12)		b Sportler (N = 12)		
	$\bar{x}$	± S.D.	$\bar{x}$	± S.D.	t
c Alter (Jahre)	24,3	2,1	27,4	2,7	3,23[b]
d Gewicht (kg)	77,4	6,9	70,3	5,8	2.76[a]
e Größe (cm)	183,2	5,1	177,9	6,8	2,14[a]
f Oberfläche (m^2)	1,98	0,1	1,87	0,1	2,80[b]
g Beinlänge (cm)	95,3	3,3	92,5	5,5	1.55
h Herz-Augen-Abstand (cm)	40,0	4,5	37,9	3,4	1,29
f_h	74,1	9,5	58,1	7,7	4,54[b]
P_s	115,3	8,9	116,5	6,4	0,37
P_d	72,8	8,9	72,2	5,2	0,22[c]
$P_s - P_d$	42,5	6.1	44,3	8,7	0.60
P_m	87,0	8,3	87,0	3,8	0,00[c]
Schneider-Index	10,8	2,3	14,1	2.2	3,37[b]
Hettinger-Index	116,8	22,9	83,3	24,5	3,25[b]
$\dot{V}O_2$max (l/min)	3,36	0,2	4,55	0,5	7,98[b]
$\dot{V}O_2$max (ml/kg/min)	43,9	3,0	64,9	5,2	11,74[b]
+ G_z bei 0,07 G/sec	6,84	0,9	6,89	0,8	0,14
+ G_z i bei 1,0 G/sec	4.92	0,9	—	-	- -

f_h = pulse frequency/min; P = arterial blood pressure mm Hg, P_s = systolic, P_d = diastolic, P_s-P_d = amplitude in blood pressure, P_m = average pressure.

a,b Significant difference in average values ([a] $0{,}05 \geq P > 0{,}01$; [b] $P \leq 0{,}01$).

c Significant difference in random sample variants in the F test.

Key:

a. students
b. athletes
c. age (years)
d. weight (kg)
e. size (cm)
f. total surface (m^2)
g. length of leg (cm)
h. heart-eye distance
i. at

the tilt table trials. /211

Table 2: Cardiovascular response after position change (comparison of athletes and untrained subjects)

		a Studenten		b Sportler		
		$\bar{x}$	± S.D.	$\bar{x}$	± S.D.	t
c Orthostase	f_h	96,6	14,3	75,2	10,3	3,94[b]
Mittelwerte	Δf_h	22,5	8,8	18,7	8,8	1,07
4.–11. min	P_s	117,2	8,9	117,6	6,6	0,13
a (Studenten:	ΔP_s	+1,8	3,6	+0,2	4,4	0,95
N = 12;	P_d	91,7	8,5	92,5	6,7	0,25
b Sportler:	ΔP_d	+18,8	5,8	+19,3	7,5	0,17
N = 10)	P_s-P_d	25,5	6,0	25,1	8,2	0,13
	ΔP_s-P_d	−17,0	3,8	−19,1	7,1	0,88
	P_m	99,0	8,0	100,8	5,7	0,60
	ΔP_m	+11,2	3,3	+12,8	5,9	0,79
d Orthostase	f_h	106,6	11,5	83,6	15,6	3,82[b]
und Apnoe	Δf_h	+31,8	10,2	+27,1	13,4	0,89
12./13. min	P_s	116,9	22,1	119,3	5,8	0,32[c]
a (Studenten:	ΔP_s	+1,5	16,7	+2,0	6,8	0,08[c]
N = 11;	P_d	88,1	11,6	92,7	9,2	0,96
b Sportler:	ΔP_d	+15,5	9,6	+19,2	9,8	0,87
N = 9)	P_s-P_d	28,8	18,5	26,7	12,5	0,30
	ΔP_s-P_d	−13,9	15,4	−18,0	14,2	0,61
	P_m	97,8	13,3	101,7	5,9	0,80[c]
	ΔP_m	10,0	9,5	14,0	6,7	1.02
e Orthostase	f_h	113,4	16,8	84,9	16,8	3,69[b]
u. Hyper-	Δf_h	39,8	12,8	30,1	12,8	1,63
ventilation	P_s	108,5	11,8	114,8	7,8	1,29
17./18. min	ΔP_s	−6,8	9,2	+1,8	9,7	1,97
a (Studenten:	P_d	85,4	9,4	91,3	7,3	1,48
N = 11;	ΔP_d	+13,6	8,1	+18,3	8,2	1,22
b Sportler:	P_s-P_d	22,3	7,6	23,5	7,8	0,34
N = 8)	ΔP_s-P_d	−20,5	8,7	−20,5	11,8	0,01
	P_m	93,7	9.8	99,0	6,3	1,33
	ΔP_m	5,9	5,9	11,3	6,6	1,86

Δf_h or Δ P: alteration in indicated values compared to the value at rest. Further explanations see Table 1.

Key:
a. students
b. athletes
c. tilt table average values in the 4th-11th minutes
d. tilt table at apnoea in the 12th/13th minute
e. tilt table and hyperventilation in the 17th/18th minute

The difference between the groups, however, apparently increases from section to section in the response of systolic blood pressure and average pressure. It is difficult to decide whether the lower values of

the untrained subjects may be attributed to the dura on of the tilt table trials or to the additional respiration tasks. Since no differences were found within the first 11 minutes after position change, it may be assumed that the subsequent differences are an expression for a lower additional stress on the athletes by apnoea and hyperventilation. /212 In spite of some considerable differences in average values it may not be completely excluded that this was accidental because of the high variation in random samples and the relatively low number of trials in each group. The t values of 1.97 and 1.86, calculated for the differences in the change of systolic and average blood pressure during hyperventilation, are in fact very close to the limit probability of 5%, usually considered sufficient in medicine, which would require a t value of 2.07 in this case. /213

With the exception of extreme behavior in preliminary fainting or fainting there is no agreement in published reports on the significance of the response of various circulatory values during position change with respect to a quantative evaluation of tilt table tolerance. Therefore we compared in Table 3 the average values of nine trials, in which the tilt table stress had to be discontinued, with 15 trials, which were continued over the prescribed time of 20 minutes without disruption. In the group of nine "fainters" there are five athletes and four unathletic persons; the second group has a corresponding composition of seven athletes and eight non-athletes. In this case the calculation of averages also excluded such values, which were measured when clinical signs of fainting were already clearly perceptible.

No significant differences can be proven in the physical dimensions, tolerance to acceleration, circulatory values at rest and the values characterizing work capacity. Of the above-mentioned values physical size, level of systolic blood pressure at rest and especially blood pressure amplitude have the largest key values, with the last even showing a probability between five and ten percent. During the tilt table trials it is also the systolic blood pressure and blood pressure amplitude, which permit prediction of the subsequent fainting by means of their significantly lower values. The results are especially remarkable in the almost completely identical response of pulse frequency.

Table 3: Physical dimensions, performance criteria and cardiovascular values at rest and after tilting (comparison of fainters and nonfainters)

		a Kein Kollaps (N 15)		b Kollaps (N 9)		
		$\bar{x}$	± S.D.	$\bar{x}$	± S.D.	t
	c Größe	179,4	7,2	182,4	4,8	1,14
	d Beinlänge	93,6	4,9	94,5	4,6	0,42
	e Herz-Augen-Abstand	38,7	4.8	39,3	2,5	0.13
	Schneider-Index	11,9	2,9	13,2	2,6	1,08
	Hettinger-Index	101,5	23,8	99,8	37,2	0,13
	$\dot{V}O_2max$ (l/min)	3,8	0,6	4.2	0,8	0,62
	$\dot{V}O_2max$ (ml/kg/min)	53,8	11,8	56,4	11,6	0,45
	$+G_z$ f bei 0,07 G/sec	6,9	0,8	6,8	0,9	0,26
	$+G_z$ f bei 1,0 G/sec	5,0	1,0	5,1	0,9	0,17
g Ruhe	h_f	65,4	13,1	67,8	9,0	0,48
	P_s	116,7	6,9	112,8	8,7	1.21
	P_d	72,1	6,9	74,6	6,5	0,87
	$P_s - P_d$	44,6	7,6	38,2	10,4	1,74
	P_m	87,1	6,0	87,3	5,4	0,14
h Orthostase Mittelwerte 4.-11. min	h_f	87,5	16,8	86,6	11,0	0,16
	Δh_f	22,1	7,4	18,8	15,6	0,73[c]
	P_s	118,0	7,2	107,6	10,8	2,86[b]
	ΔP_s	+ 1,3	4,5	5,2	11,1	2,09[a,c]
	P_d	91,1	6,8	87,8	8,4	1,20
	ΔP_d	+19,5	7,4	+13,2	9,6	1,82
	$P_s - P_d$	26,5	7,9	19,8	4,9	2,28[a]
	$\Delta P_s - P_d$	− 18,1	6,5	18,4	8,1	0,10
	P_m	99,8	5,8	94,4	8,8	1,83
	ΔP_m	+12,6	5,4	+7,1	9,4	1,66[c]

Explanations see Tables 1 and 2.

Key:
a. no fainting
b. fainting
c. size
d. length of leg
e. heart-eye distance
f. at
g. at rest
h. tilt table average values in the 4th-11th minute

The comparison presented in Table 4 of five double trials conducted with five individuals, of which one trial had to be discontinued in each case with signs of fainting, while the other was conducted normally over the twenty minute period, also show high t values in the blood pressure amplitude at rest and in systolic blood pressure and amplitude during the tilt table study. In addition the responses of diastolic pressure were significantly different from one another, leading to an almost significant difference in the change in average pressure. A behavior of pulse frequency characteristic for fainting cannot be determined here.

Table 4: Cardiovascular values at rest and on the tilt table (comparison in a double study with five persons)

		a Versuche ohne Kollaps		b Versuche mit Kollaps		
		$\bar{x}$	± S.D.	$\bar{x}$	± S.D.	t
c Ruhe	f_h	69,2	12,3	70.2	10.6	0,14
	P_s	114,0	10,8	110,6	9,7	0,52
	P_d	75,4	9.2	77.8	5.4	0,50
	$P_s - P_d$	38,6	2,2	32,8	7,9	1,59[c]
	P_m	88.2	9,4	88,8	6,1	0,12
d Orthostase Mittelwerte 4.—11. min	f_h	89,4	19,1	85.2	7,0	0.46
	Δf_h	+20,2	10.8	+15,0	15,6	0,60
	P_s	113,6	10,1	103.2	9,8	1,65
	ΔP_s	—0,4	2,9	—7,4	13,0	1,17[c]
	P_d	91,6	10,9	84,6	8,1	1,15
	ΔP_d	+16.2	2,8	+6,8	7,9	2,51[a, c]
	$P_s - P_d$	22,0	2,0	18,6	2,7	2,26[a]
	$\Delta P_s - P_d$	—16,6	3,1	14.2	7,2	0,69
	P_m	99,0	10,9	90,8	8.4	1,34
	ΔP_m	+10,7	3,0	+2.0	9,0	2,02[c]

Explanations see Tables 1 and 2.

Key:
a. trials without fainting
b. trials with fainting
c. at rest
d. with tilt table average values in the 4th-11th minute

Table 5: Coefficients of product-moment correlation (r)

		a Größe	b Herz-Augen-Abstand	$\dot{V}O_2max$ (l/min)	c $+G_z$ bei 0,07 G/sec
	b Herz-Augen-Abstand	+0,74[b]			
	$\dot{V}O_2max$ (l/min)	—0,07	—0,03		
	c $+G_z$ bei 0,07 G/sec	—0,22	—0,41[a]	—0,04	
d Ruhe	h_f	+0,04 (—0,03)	—0,21	—0,68[b]	+0,20
	P_s	+0,13 (+0,10)	+0,19	+0,17	+0,48[a]
	P_d	—0,07 (—0,24)	—0,14	—0,04	+0,51[a]
	P_s-P_d	+0,20 (+0,40)	+0,33	+0,22	+0,11
	P_m	—0,01 (—0,04)	—0,02	+0,04	+0,55[b]
e Orthostase Mittelwerte 4.—11. min	h_f	+0,12 (+0,12)	—0,31	—0,61[b]	+0,03
	Δh_f	+0,16 (+0,10)	—0,24	—0,24	—0,13
	P_s	+0,27 (—0,15)	+0,33	—0,02	+0,52[a]
	ΔP_s	+0,34 (—0,38)	+0,35	—0,29	—0,03
	P_d	+0,23 (—0,15)	+0,02	+0,14	+0,52[a]
	ΔP_d	+0,28 (+0,03)	+0.11	+0,03	+0,08
	P_s-P_d	+0.07 (—0,08)	+0,39	—0,18	+0,06
	ΔP_s-P_d	+0,05 (—0,56)	+0,12	—0,24	—0,12
	P_m	+0,34 (—0,15)	+0,24	+0,20	+0,50[a]
	ΔP_m	+0,47[a] (—0,11)	+0,29	+0,19	—0,05

The coefficients calculated from nine fainting trials are given in parenthesis. Further explanations see Tables 1 and 2.

Key:
a. quantity
b. heart-eye distance
c. at
d. at rest
e. tilt table average values in the 4th-11th minute

Finally, using the coefficients of the product-moment correlation, Table 5 provides a survey of the mathematical relationship of the values to one another, of special importance to the subject of this report. As expected, there is a positive relationship between the measures of length, the distance from head to foot and the distance from heart to corner of the eye. A certain degree of independence of these two values from one another, however, becomes clear in the differing relationship of the two values to acceleration tolerance; it is negative in both cases as expected, but proves to be weak and not significant in the case of physical size, while significant and noteworthy in the case of the heart-eye distance. On the other hand, the physical size shows the more closely related and partially statistically significant correlation to response of the circulation during tilt table trials: when the tilt table trial runs a normal course, this dependence is positive,

i.e. blood pressure increases according to necessity, during position change with increasing size of the subject; however, it becomes negative, when only the results of the trials are applied to correlation calculation, in which the stress was discontinued due to fainting. The differences between the coefficients of the fainters in parenthesis and those of the remaining trials are almost significant for ΔP_s and $\Delta P_s - P_d$ with a probability of $0.1 > P > 0.05$. The findings may also be mentioned in this connection, that the correlation coefficient for the relationship of ΔP_s to physical size is clearly negative and almost significant during the hyperventilation in the third section of the tilt table trials with r = -0.39 even for the trials, which were continued for 20 minutes with the total stress without disruption.

Figure 1 shows the linear regressions of the average blood pressure responses during the 4th-11th minutes of the tilt table compared to physical size. These are based on the following mathematical relationships (the regression equations with the "standard deviations estimation" calculated individually from the nine fainting trials are in parenthesis): for ΔP_s: $y = -35.91 + 0.205x$; $S.D._{yx} = 3.69$ ($y = 162.88 - 0.921x$; $S.D._{yx} = 10.26$) - for ΔP_d: $y = -31.12 + 0.279x$; $S.D._{yx} = 6.07$ ($y = 2.24 + 0.060x$; $S.D._{yx} = 9.63$) - for $\Delta P_s - P_d$: $y = -28.55 + 0.066x$; $S.D._{yx} = 9.13$ ($y = 160.68 - 0.982y$; $S.D._{yx} = 6.74$) - for ΔP_m: $y = -49.79 + 0.343$; $S.D._{yx} = 4.18$ ($y = 38.12 - 0.173x$; $S.D._{yx} = 9.23$).

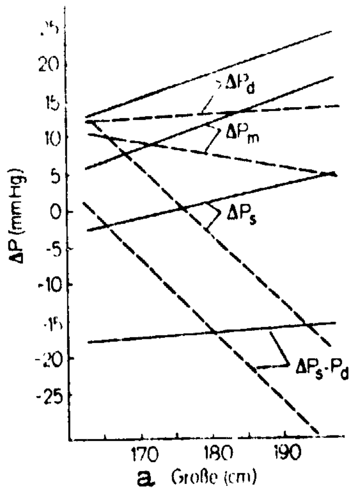

Figure 1: The linear regression of blood pressure response during tilt table trials as a function of physical size (---fainting trials).

Key:
a. size (cm)

As Table 5 further shows, the dependence of maximum oxygen intake solely on level of pulse frequency with a negative find is remarkable. This relationship exists to approximately the same degree for pulse at rest as well as for the pulse values determined during the 4th-11th minutes of the tilt table trials and may also be similarly proven for subsequent sections. The relationship to Δh_f ($r = -0.24$) was at the same time only weak and lead to the assumption that the dependence of $\dot{V}O_2$ max to the level of stress pulse arises essentially from the relationship to the pulse at rest. We therefore calculated the "partial correlation" between the tilt table pulse and the $\dot{V}O_2$ max according to the usual equation [10] independent of pulse at rest and obtained $r_{12.3} = -0.05$ for the first section of tilt table stress and similarly negative low coefficients for the two subsequent sections. /216

The differences between athletes and untrained persons in the group comparison of cardiovascular response to hyperventilation already obvious in Table 1 lead us to calculate the mathematical relation of maximum oxygen intake to the cardiovascular values for the hyperventilation section in addition to the correlations listed in Table 5. The results showed, that the relationship was significantly negative at this time between the pulse frequency response (Δh_f) and $\dot{V}O_2$ max at $r = -0.43$ and that ΔP_s ($r = +0.26$) and ΔP_m ($r = +0.33$) with a positive sign and larger coefficients in contrast to the first stress section also supported the conclusion that the response becomes more favorable with improved fitness, the meaning of the favorable response defined here as a smaller increase in pulse, larger increase or less decrease in P_s or larger increase in P_m.

It becomes apparent that there is no noticeable positive relationship of the coefficients listed in Table 5 for the maximum O_2 intake to physical size; this would have been expected and has already been proven several times previously. It did not become apparent in our tables of values, because the large differences in individual physical fitness masked the dependence of the two values upon one another in the individual groups. The correlation coefficient of $r = +0.79$ in the case of the students and of $r = +0.46$ in the case of the athletes made it apparent via the corresponding "measure of determination" (r^2), that the

differences in $\dot{V}O_2$ max may be explained solely by means of physical size to 62% in the first group and to more than 20% in the second group. The slightly negative coefficient of r = -0.07 results for the entire values from the circumstance, that the athletes with the larger $\dot{V}O_2$ max are on the average smaller.

For the acceleration times Table 5 shows in addition to the above-mentioned negative dependence on heart-eye distance also significant positive relationship to blood pressure level, which exists to approximately the same degree in the systolic, diastolic and average blood pressure level at rest and after position change. /217 As in the case of the relationship of $\dot{V}O_2$ max to the pulse frequency during tilt table stress the assumption may be made here due to the lack of a noticeable correlation between acceleration tolerance and ΔP, that the relationship discovered during stress stems mainly from relation of blackout threshold to blood pressure at rest. The "partial correlations" calculated for the stress blood pressure independent of blood pressure at rest confirm this assumption. It amounts to $r_{12.3}$ = +0.24 (instead of r = +0.25) for $+G_z$ to P_s, to $r_{12.3}$ = +0.30 (instead of r = +0.25) for P_d and only to $r_{12.3}$ = +0.17 (instead of r = +0.50) for P_m; the coefficients of partial correlation are no longer significant.

Figure 2 shows the linear regressions of the two length measurements, the blood pressure at rest and the maximum oxygen intake to the acceleration tolerance (for an increase in acceleration of 0.07G per second). These are based on the following regression equations:

size: $y = 11.74 - 0.027x$; $S.D._{yx} = 0.792$
heart-eye distance: $y = 10.27 - 0.087x$; $S.D._{yx} = 0.779$
$\dot{V}O_2$ max: $y = 7.09 - 0.046x$; $S.D._{yx} = 0.822$
P_s: $y = 1.58 + 0.047x$; $S.D._{yx} = 0.680$
P_d: $y = {}^{\cdot}.03 + 0.055x$; $S.D._{yx} = 0.665$
P_m: $y = 0.81 + 0.070x$; $S.D._{yx} = 0.649$.

For the heart-eye distance the regression was also shown for the acceleration tolerance at an increase in acceleration of 1G/sec. The corresponding equation is: $y = 8.87 - 0.097x$; $S.D._{yx} = 0.793$; the correlation coefficient is r = -0.47, the number of subjects amounted to 13 here.

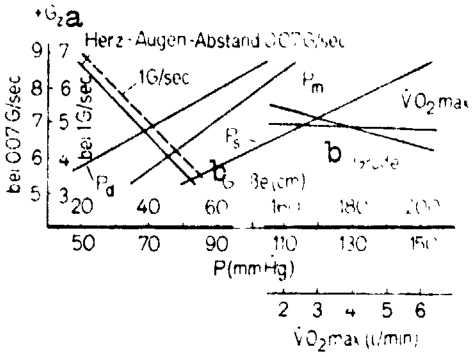

Figure 2: The linear regressions of acceleration tolerance to physical size, blood pressure at rest and maximum O_2 intake ($+G_z$ tolerance at 1G/sec. increase only for heart-eye distance)

Key:
a. heart-eye distance
b. size

Discussion of Results

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The "normal" reaction to the position change of 90 degrees was an increase in average pulse frequency by 20 beats to 86/min (+30%) in a period of 11 minutes, an increase in systolic blood pressure by 1 mm to 117 mm Hg ($< +1\%$), an increase in diastolic pressure by 19 mm to 92 mm Hg (+26%) and an increase in average pressure by 12 mm to 99 mm Hg (+14%). At the same time the blood pressure amplitude was reduced by 18 mm to 25 mm Hg (-42%).

As in the intraarterial measurements done by Stevens [41] in the case of those persons showing signs of fainting during tilt table investigations, the blood pressure was already reduced at rest compared to the control average - the systolic pressure by 4 mm (3.5%) and the amplitude by about 6 mm Hg (14%). These findings gain in importance in spite of the lack of statistical significance, because they were ascertained in persons of a group to a similar degree and could be compared with one another using the results of two trials with differing course. The difference in blood pressure values already at rest between trials with and without fainting became more clearly defined after position change by a definite reduction in systolic pressure and a somewhat greater narrowing in amplitude in the second group; finally the systolic pressure already dropped by an average of almost 10%, the amplitude by 15% and the average pressure by 6-10% one to two minutes, before external

clinical signs were noticed compared to those persons showing no disturbances during the whole time of the examination.

In contrast to the blood pressure the pulse frequency first demonstrated clearly deviating responses from standards, when fainting was imminent. However, there was already a tendency in fainters for less increase or leveling off at a lower value. The average differences found between the groups, however, are far from being statistically significant due to variations in response causing a large standard deviation. The pulse rate therefore generally proved less suitable for the acquisition of individual differences in tilt table tolerance in our studies in agreement with a portion of the older and more recent published reports [1, 2, 4, 15, 41].

The assumption has been presented at various times, that the quality of cardiovascular regulations during position change could depend on physical fitness of the subjects. This question has been answered positively by Graybiel and McFarland [15] and in the negative by Allen et al. [1] on the basis of differing experimental results. /219
The connection of poor physical fitness with a greater inclination to faint is also supported by the lower pulse rate determined in athletes on the tilt table [45, 48], considered the expression for a more stable, more economical and therefore "better" cardiovascular regulation [28], analogous to the behavior of trained persons during physical work. We have already proven in an earlier publication for lack of oxygen, that the pulse rate level in acute hypoxia may depend to a significant degree on maximum oxygen intake during work and therefore on physical fitness, but that it has practically no relation to the tolerance for lack of oxygen at the same time and therefore cannot be a measure for this quantity [23]. The same now applies to the tilt table stress. In this case the rate during tilt table trials is also closely and significantly dependent on the capacity for oxygen intake during strenuous muscle work, which, as the lower "partial" coefficient of $r = -0.05$ proves, stems almost exclusively from the rate differences already existing in the horizontal position. The larger cardiovascular reserves apparent in bradycardia at rest, doubtlessly important for maximum capacity for muscular work, does not come into play in the tilt table stress; this

is as a rule conditionally connected to a greater tolerance. Our experimental results clearly demonstrate that very large differences at times in the physical fitness of the subjects, expressed by oxygen intake, do not effect the tolerance to sudden position change - with the possible exception of that situation in which the circulation is subjected to the additional stress of simultaneous hyperventilation. We therefore agree with Gadermann, Jungmann and Metzner [11], that even such a hard, year-long cardiovascular training, as is practiced by top athletes in endurance sports, does not decisively alter the regulative processes, counteracting a reduction in volume of arterial blood upon position change of inactive organism.

This determination, however, does not alter the fact that measures for reducing condition, such as lack of activity, bed rest and weightlessness together with a change in blood pressure and pulse rate response, can definitely reduce the tolerance to sudden position change [5, 18, 31, 42, 44, 46]. Changes in tissue tension, in tone of the veins and in peripheral resistance may play a role in addition to reduction in plasma volume [42]. As our comparison showed in those persons, /220 fainting during one trial but maintaining the vertical position in a second without disruption over the entire time, a relatively slight reduction in blood pressure values at rest already suffices to reduce the blood pressure during tilt table stress below the response range considered normal, indicated in published reports in agreement with our own results as an average of up to -10% for systolic blood pressure and u. to -50% for amplitude [1, 2, 15, 41].

The connection of a change in tilt table tolerance to alterations in pulse rate response during tilt table stress, however, is also no proof of a causal dependency of the two quantities upon one another. The responses on the tilt table appear parallel mainly because inactivity, for example, has a reducing effect on tilt table tolerance as well as on physical fitness. According to this the reduction in tilt table tolerance is demonstrated in the change in blood pressure response, the decrease in physical fitness and also in a change in pulse rate response.

Very little information is available on the dependence of tilt table tolerance to stature. Brehm and Wezler [2] indicate that the average arterial pressure would be approximately the same for large and small persons, so that in the vertical position, when the blood pressure is reduced, the brain would receive an insufficient supply of blood in larger persons due to the larger heart-brain distance. We also found that the blood pressure at rest measured in the horizontal position, especially the average pressure, was generally not dependent on physical size; however, after position change some significant correlations were calculated, with differing signs, as already mentioned, according to the course of the experiment. While the systolic pressure and above all the average pressure was related positively to size and therefore to hydrostatic pressure difference in heart-brain in those persons showing no signs of fainting over the 20 minutes, there was a negative dependence of blood pressure to physical size in fainters, but the decrease in amplitude seems to be caused more by differences in extent of blood shift and probably by differences in the length of the part of the body involved [4].

The acceleration tolerance, measured as central loss of vision in the case of positive acceleration forces acting in the direction of the longitudinal axis of the body, corresponds well to the results of our earlier experiments [21, 23] and with $4.9+G_z$ for the rapid increase of 1G/sec lies approximately in the middle of the large-scale experimental results of Howard [17] with $5.0+G^z$ and the $4.7+G_z$ quoted by White [49] and Meehan [29]. With a tolerance difference of 1.9G between the two /221
differing rates of 1G/sec and 0.07G/sec our measurements agree furthermore agree exactly with the results of Edelberg et al. [7] and in close approximation to the 2.1G from our own experiments [21, 23].

The question about a connection between $+G_z$ tolerance and physical fitness has been answered positively by Wessel [48] on the basis of experimental results. This is supported mainly by the parallel alteration of the two values after a period of training and inactivity. Their results are hardly convincing for us, because we feel they were gained by means of inadequate methods: the Harvard Step Test is not a good basis for the performance of circulation and respiration, above all in

the single execution (among others see [23, 38]), nor is the measurement of amount of blood in the ear and the pulse rate during or after acceleration accurate for determining acceleration tolerance in our opinion. We must repeat our reservations on the basis of our own experience in connection with the tilt table study, expecially for pulse rate. The rate values measured during acceleration may also show a close correlation to physical fitness (here: $\dot{V}O_2$ max), but only a weak connection to the central loss of vision (see also Howard [17], p. 606). The observation made by Wessel [48] after periods of athletic training of a simultaneous reduction in pulse increase during work and acceleration stress may therefore probably only be considered as the effect of training, but not as an increase in acceleration tolerance. Meehan and Jacobs [30] were already not able to determine a noticeable relationship to physical fitness in acceleration tolerance employing the loss of peripheral and central vision; however, the performance capacity measured in the Harvard test and during physical training in these studies was hardly satisfying. After determination of functional capacity of circulation and respiration via the maximum oxygen intake and comparison of persons with large differences in performance, we believe that the question can definitely be answered in the negative about the dependence of acceleration tolerance on training condition and physical fitness, as was already done for the relation of tilt table tolerance to physical fitness. This statement is not limited by the determination that a "weak" to "noticeable" connection between the results of the Schneider test and the blackout threshold was calculated previously in the case of untrained persons [21, 23, 50] and here in the case of athletes with r = 0.36, since this test is in our opinion hardly suitable for the measurement of individual physical fitness [21, 23, 38]. /222

In our trial series there was also practically no connection between acceleration tolerance (measured as loss of central vision in the centrifuge) and the tilt table tolerance (measured via cardiovascular response and fainting in position change), if the noticeable correlation of CLL threshold to the level of blood pressure is not taken into consideration, which - as shown above - stems solely from the blood pressure values at rest. This result corresponds to the findings of other authors in experiments with similar problems, but differing

methods [20, 25, 37]. With the exception of the postulation of a connection on the basis of theoretical considerations [15, 27] only a significant coefficient (r = -0.44) determined by Estes [8] for the relationship of CLL threshold to the alteration in pulse rate on the tilt table stands against the negative results, but this provides little conclusive force for a genuine connection between the two tolerances. The processes of reflection, counteracting a reduction in filling of arterial vessels subject to forces of gravity parallel to the longitudinal axis of the body, are numerous [13, 35]; however, these may be reduced essentially to two mechanisms with respect to speed of operation: a peripheral vasoconstriction and increase in heart beat begins as immediate regulation via the pressure receptors, in addition liquid is subsequently retained in the blood vessel system through the anti-diuretic hormone of the hypothysis, the aldosterone of the cortex of the suprarenal body or the kidney. It is evident that only the first mechanism can act during an acceleration stress increasing in a few seconds up to fainting, but that both mechanisms may be decisive for "success" during a stress of 1G of 10, 20 or 30 minutes.

The individual level of acceleration tolerance was determined in our trial series to a significant degree, first by the distance of the heart beat peak to the corner of the eye, and secondly by the arterial blood pressure at rest; however, the correlation coefficient of r = -0.41 for the relationship of heart-eye distance to blackout threshold was smaller than the value supplied by Hunter [19] of r = -0.77. Whether variations in method might have caused the result differences cannot be decided here, since the work done by Hunter was not available in the original. Consideration must of course be made of the fact that determination of increasing blood pressure level via the distance of heart beat peak to the left corner of the eye contains many possibilities for error. It is therefore quite possible that the values would be closer, using a more exact determination of length, possibly even X-rays.

The coefficient calculated for the relation of blood pressure at rest to the CLL threshold deviates from published values between r = 0.11-0.36 [8, 30, 50]; however, it must be taken into consideration here, that the acceleration tolerance was determined in the studies available /223

for comparison in trials of 10-15 sec. with increases of $> 0.28G/sec.$ - the explanation for any appreciable dependence of the blood pressure at rest on acceleration tolerance seems simple, since it had been determined that persons with a high acceleration tolerance generally exhibit a higher noradrenalin level not only during, but also already in the control period shortly before being subject to acceleration [6, 14, 31, 40]. The fact that the highest coefficients (calculated by us and Estes [8]) are based on blood pressure values at rest, not measured in a sitting position before the acceleration experiment, but rather in a prone position before the tilt table trial, does not facilitate understanding of relationships, unless the assumption is made, that the dependence of tolerance on blood pressure becomes more evident under these circumstances because the "tension" leading to the secretion of noradrenalin is stronger in expectation of the position change than it is before the trial in the centrifuge. The curves recently published by Offerhaus and Dejongh [35], demonstrating the differences in the level of urine noradrenalin level before tilt table stress and centrifruge stress, may actually be interpreted in this manner.

As was mentioned above, two quantities were determined in our subjects, contributing to the level of acceleration tolerance, so that it was possible to calculate a coefficient of multiple correlation [10]. This amounts to $R_{1.23} = 0.70$ for the dependence of blackout threshold on the combination of heart-eye distance and systolic blood pressure at rest and $R_{1.23} = 0.68$ for the heart-eye distance and the average arterial pressure as independent values determining acceleration tolerance. The multiple measure of determination corresponding to the two coefficients of correlation, $R^2_{1.23} = 0.492$ for the combination with P_s and $R^2 = 0.461$ for the combination with P_m, permit the statement that in our experiment almost 50% of interindividual variations in blackout threshold may be explained in numbers by differences in the distance of the heart to the eye together with differences in the systolic blood pressure at rest; the explanable portion of variation for the combination of measure of length with average arterial pressure amounts to 46%.

The statistical relationship between the three latter-mentioned variables may be expressed mathematically by the equation of multiple

regression (see also J. P. Guilford, Fundamental statistics in psychology and education, Fourth International Student Edition, p. 396, New York, McGraw Hill Book Co. 1965). /224

In the equation y signifies the blackout threshold in G for the increase of 0.07G/sec., x_1 the heart-eye distance in centimeters and x_2 the blood pressure at rest measured while prone in mm Hg. If the heart-eye distance and blood pressure at rest of a subject are known, the expected blackout threshold may be predicted with a standard deviation of ± 0.56G. According to Guilford (see also p. 377) such a prediction would be at least 30% better than a prediction without knowledge of the relationships calculated here.

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